Journal of Naval Sciences and Engineering
2021, Vol. 17, No. 2, pp. 395-411
Naval Architecture and Marine Engineering/Gemi İnşaatı ve Gemi Makineleri Mühendisliği

RESEARCH ARTICLE

** An ethical committee approval and/or legal/special permission has not been required within the scope of this study.*

CHARACTERIZATION OF WELDING ZONE OF SHIPBUILDING STEEL UNDERWATER WELDED AT DIFFERENT DEPTHS*

Dursun Murat SEKBAN[1]
Abdulhabib NACAR[2]

[1]*Karadeniz Technical University, Department of Marine Engineering Operations, Trabzon, Turkey,*
msekban@ktu.edu.tr; ORCID: 0000-0002-7493-1081

[2]*Karadeniz Technical University, Department of Naval Architecture and Marine Engineering, Trabzon, Turkey,*
abdulhabibnacar@gmail.com; ORCID: 0000-0002-9820-0021

Received: 09.08.2021 **Accepted: 18.10.2021**

Dursun Murat SEKBAN, Abdulhabib NACAR

ABSTRACT

Although welding operations are mostly carried out in atmospheric conditions in shipbuilding, underwater welding is also used intensively in order to speed up the repair processes in the underwater parts of the ships. It is known that due to the nature of the underwater welding, there are significant differences in the weld area compared to the weld made under atmospheric conditions. The most important factor that creates this difference is that the cooling rates achieved after welding contain significant differences compared to welding performed under atmospheric conditions. On the other hand, it is known that the depth of the underwater welding has a significant effect on this cooling rate. In the literature, it is seen that studies on underwater welding are extremely limited. On the other hand, no study has been found that has examined the effect of depth on the microstructure and mechanical properties during underwater welding of steels used in shipbuilding. In this context, in this study, a steel used extensively in shipbuilding was joint with atmospheric conditions welding and underwater welding (two varying depths), and the microstructure and mechanical properties of the welded area were examined comparatively.

Keywords: *Shipbuilding, Welding, Underwater Welding, Mechanical Properties.*

FARKLI DERİNLİKLERDE SUALTI KAYNAĞI UYGULANAN GEMİ İNŞA ÇELİĞİNİN KAYNAK BÖLGESİNİN KARAKTERİZASYONU

ÖZ

Gemi inşaatında kaynak işlemleri yoğunlukla atmosferik şartlarda yapılsa da, gemilerin su altında kalan kısımlarındaki tamir işlemlerini hızlandırmak adına sualtı kaynağı da yoğunlukla kullanılmaktadır. Su altı kaynağının doğası gereği kaynak bölgesinde atmosferik şartlarda yapılan kaynağa göre önemli farklar içerdiği bilinmektedir. Bu farkı oluşturan en önemli etken kaynak sonrasında erişilen soğuma hızlarının atmosferik şartlarda yapılan kaynağa göre önemli farklar içermesidir. Öte yandan bu soğuma hızına su altı kaynağının yapıldığı derinliğin de önemli oranda etki ettiği bilinmektedir. Literatürde sualtı kaynağı ile ilgili çalışmaların son derece sınırlı olduğu görülmektedir. Öte yandan gemi inşaatında kullanılan çeliklerin sualtı kaynağı sırasında derinliğin içyapı ve mekanik özellikler üzerindeki etkisini ayrıntılı olarak incelemiş bir çalışmaya rastlanmamıştır. Bu bağlamda bu çalışmada gemi inşaatında yoğun olarak kullanılan bir çeliğe atmosferik şartlarda ve değişen iki derinlikte sualtı kaynağı yapılarak kaynak bölgesinin içyapı ve mekanik özellikleri (sertlik, mukavamet, eğme ve darbe dayanımı) karşılaştırmalı olarak incelenmiştir.

Anahtar Kelimeler: *Gemi İnşaatı, Kaynak, Su Altı Kaynağı, Mekanik Özellikler.*

1. INTRODUCTION

Ships are built by joining plates and profiles of varying thickness and dimensions to each other with varying welding methods. During the ship's construction process, welds are made under atmospheric conditions. The welds made during the initial construction process vary according to variables such as the thickness of the plates used or the ship area to be welded. When the welding methods used in the shipbuilding process are examined, it is observed that gas metal arc welding; submerged arc welding and electrode arc welding are the 3 most used welding methods. On the other hand, after the first construction process, welding processes are also needed intensively in repair processes.

Welding operations during repair can be done under atmospheric conditions, as well as underwater welding processes are used intensively in order to speed up the process in underwater repair operations of the ship. When the history of underwater welding is examined, it is seen that this welding method gained great importance during the 1.World War. The underwater welding, which started to be used to repair the underwater damage of warships, continues to be used intensively in the construction of oil platforms, the welding of underwater pipelines and the repair of the underwater parts of the ships with the advancement of technology. It is known that the weld area of the weld made underwater differs greatly from the weld made under atmospheric conditions. As it is known, phase changes can occur in steels after welding and the cooling rate affects these changes significantly (Bhadeshia & Svensson, 1993; Boumerzoug, Derfouf & Baudin, 2010; David, Babu & Vitek, 2003; Eroğlu, Aksoy & Orhan, 1999; Gharibshahiyan, Raouf, Parvin & Rahimian, 2011; Gould, Khurana & Li, 2006; Grong & Matlock, 1986; Lars-Erik, 2017; Magnabosco, Ferro, Bonollo & Arnberg, 2006; Zhang, Jing, Xu, Han & Zhao, 2016). These changes in the microstructure also significantly affect the mechanical properties of the weld area (Boumerzoug et al., 2010; Gharibshahiyan et al., 2011; Liu et al., 2020). Again in this context, it is known that the depth at which the underwater welding is made makes a difference on the characteristics of the weld area by affecting the burning carbon rate (İmdat, Kaya & Kahraman, 2018). When the studies in the literature are examined, it is seen that the studies examining the microstructural and mechanical properties of the weld area after the underwater welding are extremely limited. (Houldcroft, 1990; Kanjilal, Pal & Majumdar, 2006, 2007; Lee, Chandel & Seow, 2000; McPherson, Chi & Baker, 2003; Murugan & Gunaraj, 2005; Pandey, Bharti & Gupta, 1994). On the other hand, after the application of this welding method to the steels used in shipbuilding, it is seen from the literature that a detailed microstructure and mechanical property analysis was not carried out. In this context, in this study, a steel used extensively in shipbuilding was welded at atmospheric condition and underwater with two different depths. After the welds, the microstructural examinations of the structure formed in the weld area under changing conditions were made. After the microstructure examinations, the hardness, strength, bending strength and impact toughness properties of the weld zone were examined comparatively in all conditions.

2. EXPERIMENTAL PROCESS

Within the scope of the study, low-medium strength shipbuilding steel with the dimensions of 200 mm x 40 mm x 8 mm, which is used extensively in shipbuilding, was used. The chemical composition of the steel used is shown in Table 1.

Table 1. Chemical composition of the steel used in the study (% wt.).

C	Mn	P	S	Si	Cu	Cr	V	Mo	Fe
0,17	0,66	0,017	0,01	0,19	0,05	0,1	0,04	0,12	Balance

Before welding, the welding groove was opened to the plates in all conditions and welding processes were carried out by same welder so that there is no difference between the welds due to the welder. Welding processes under atmospheric conditions and underwater were carried out using rutile electrodes. Electrodes with a diameter of 4 mm were used and the electrodes were covered with paraffin material to provide insulation. All of the underwater welds were carried out in the marine environment. On the day of the underwater weldings done, the sea water temperature was 29 ^{o}C and the sea salinity rate was 28%. In order to examine the effect of different depths in the weld area, welding processes were carried out separately at 1 meter and 5 meter depths.

Optical microscope examinations were made on the samples extracted from the weld area using wire erosion in order to carry out the microstructure examinations of the weld area after welding. Before the optical microscopy examinations, the samples were sanded, polished, and immersed in 3% Nital solution for 10 seconds, respectively.

After welding, the mechanical properties of the samples were investigated using hardness, tensile, 3-point bending and impact tests. Hardness tests were carried out using the Vickers hardness measurement method in struers brand duramin 3 model hardness device. During the experiments, the compression load of the penetrating tip was 500 g and the waiting time under load was 10 s. Tensile tests were carried out with at least 3 replicates at room temperature and the average strength and elongation values are given in the tables. The tests were performed using an Instron-3382 electro-mechanical testing frame with a video type extensometer at a quasi-static strain rate of $5.4\text{x}10^{-4}$ s^{-1}. The impact tests were similarly carried out at room temperature and in 3 repetitions, and the average values were determined. Impact experiments were carried out on a Charpy notch impact machine with a 50 J capacity Instron Ceast. Three-point bending tests were performed on an Instron 3220 universal testing machine at room temperature with a gauge speed of 1 mm/min. The amount of force-deflection applied to the sample during the experiment was continuously recorded with the help of a computer, and the bending force and maximum force deflection values were determined.

3. RESULTS AND DISCUSSIONS

3.1. Microstructure

The microstructures of the base, the sample welded under atmospheric conditions and the samples welded underwater at different depths are given in Figure 1. As can be seen from Figure 1a, the microstructure of the preweld steel consists of coarse-grained ferrite and pearlite structures. It is also clearly seen from this image that there is some orientation in the direction of the rolling mill as expected in the perlite structure of the steel supplied as a hot rolled product. It is observed that the grains are slightly finer than base after welding in atmospheric conditions (Figure 1b). This situation is thought to be caused by the transformations during the cooling of the rising temperature during welding. Also, it is clearly seen that the microstructures after welding in water are oriented in the direction of cooling according to the base material with the effect of rapid cooling (Figure 1 (c-d)).

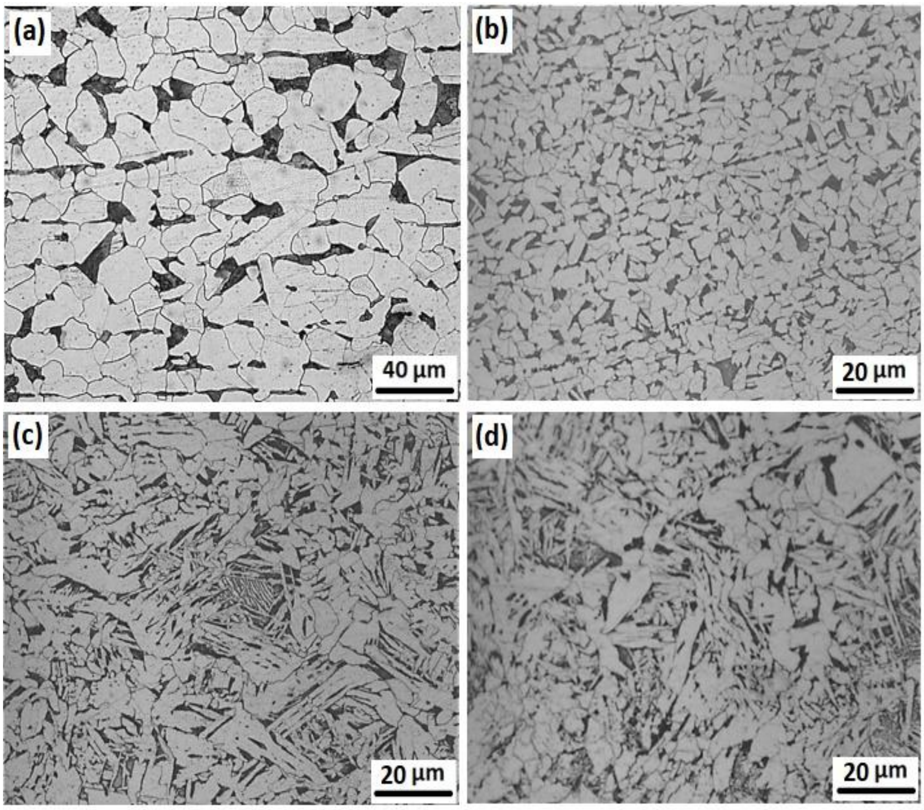

Figure 1. Microstructure of the base, the sample welded under atmospheric conditions and the samples welded in water.

3.2. Mechanical Properties

The hardness values obtained from the weld zone of the base, the sample welded under atmospheric conditions and the samples welded underwater at different depths are given in Table 2. As can be seen from the table, the hardness values increased as a result of the relatively thinned grain size after welding under atmospheric conditions. When we look at the underwater welds, it has been determined that the hardness values reach the highest levels due to both the increase in grain refinement and the effect of possible hard and brittle phases formed during underwater welding. On the other hand, it has been determined that the hardness decreases as the depth at which the weld is made underwater increases. The reason for this situation is that as the depth of the weld increases, the amount of carbon burned during welding increases (İmdat, Kaya & Kahraman, 2018). This situation, which caused a decrease in the amount of carbon in the structure, caused this decrease in hardness values.

Table 2. The hardness values obtained from the weld zone of the base, the sample welded under atmospheric conditions and the samples welded underwater at different depths.

Condition	**Hardness (Hv)**
Base	135±4
Welding in Atmospheric Conditions	175±6
1 Meter Deep Underwater Welding	220±7
5 Meter Deep Underwater Welding	205±5

The strength and elongation values obtained from the weld zone of the base, the sample welded under atmospheric conditions and the samples welded underwater at different depths are shown in Figure 2 and Table 3. As can be seen, after the grain size decreased as a result of welding performed under atmospheric conditions, the strength values increased while the elongation values decreased. The reason for this situation is the decrease in grain size after welding. As it is known, the decrease in grain size causes an increase in the strength of steels (Hajian et al., 2015). Increasing grain boundary ratio after grain refinement increases the strength values by preventing the movement of dislocations during plastic deformation. The increase in strength values after welding in atmospheric conditions can be explained in this way. On the other hand, increasing grain boundary amount per unit area after decreasing grain size caused a decrease in the elongation values by preventing the movement of dislocations, and the elongation values decreased after welding performed under atmospheric conditions (Hajian et al., 2015). It has been determined that there is a decrease in the strength and elongation values as a result of the amount of burning carbon in the welds made in water. As expected as a result of decreasing carbon amount after increasing weld depth, it can be seen that there is a higher amount of decrease in strength values.

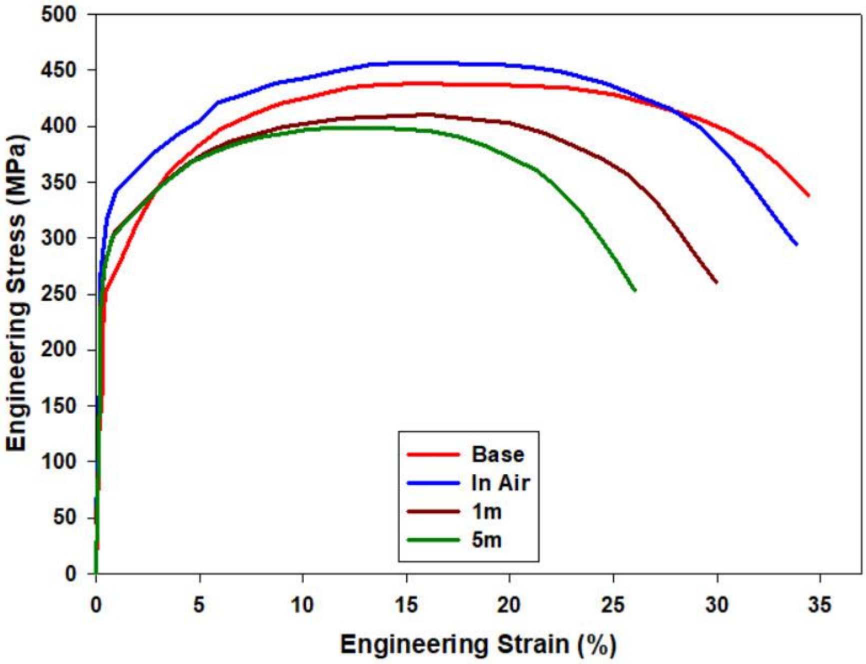

Figure 2. Strength and elongation curves obtained from the weld zone of the base, the sample welded under atmospheric conditions and the samples welded underwater at different depths.

Table 3. Strength and elongation values obtained from the weld zone of the base, the sample welded under atmospheric conditions and the samples welded underwater at different depths.

Condition	Tensile Strength (MPa)	Elongation (%)
Base	441±7	37
Welding in Atmospheric Conditions	457±9	35
1 Meter Deep Underwater Welding	411±8	31
5 Meter Deep Underwater Welding	397±10	26

Bending forces and deflection values at maximum force obtained from the weld zone of the base, the sample welded under atmospheric conditions and the samples welded underwater at different depths are given in Table 4. It is seen that the increased strength values after welding in atmospheric conditions are also reflected in the bending force. Similarly, it was determined that the deflection values at maximum force decreased as a result of decreasing elongation values. When we look at the welds made underwater, it has been determined that the decreasing strength values as a result of the decreasing carbon ratio cause a decrease in the bending force. Deflection values at maximum force also decreased as a result of welding in water.

Table 4. Bending forces and deflection values at maximum force obtained from the weld zone of the base, the sample welded under atmospheric conditions and the samples welded underwater at different depths.

Condition	**Bending Force (N)**	**Deflection (mm)**
Base	390±6	6,52±0,2
Welding in Atmospheric Conditions	441±8	6,04±0,3
1 Meter Deep Underwater Welding	404±11	5,91±0,2
5 Meter Deep Underwater Welding	375±14	5,83±0,1

The impact toughness values obtained from the weld zone of the base, the sample welded under atmospheric conditions and the samples welded underwater at different depths are given in Table 5. As can be seen from the table, it can be seen that the impact toughness value increased compared to the main structure as a result of welding performed under atmospheric conditions. Although there is a slight decrease in elongation values after welding in atmospheric conditions, it is thought that the relatively high increase in strength values causes an increase in impact toughness. On the other hand, since both strength and elongation values decreased after welds in water, the impact strength values decreased as expected compared to the main structure. It was determined that the lowest impact strength values were obtained under this condition, since both the strength and elongation values decreased with the increase in the depth of welding.

Table 5. Impact toughness values obtained from the weld zone of the base, the sample welded under atmospheric conditions and the samples welded underwater at different depths.

Condition	Impact Toughness (Joule)
Base	8,3±0,6
Welding in Atmospheric Conditions	8,7±0,7
1 Meter Deep Underwater Welding	7,4±0,4
5 Meter Deep Underwater Welding	6,2±0,5

4. CONCLUSION

Within the scope of the study, low-medium carbon shipbuilding steel, which is used extensively in shipbuilding, was welded under atmospheric conditions and underwater at two different depths, and the microstructural and mechanical properties obtained in the welding region were examined comparatively. The general results obtained in the study are summarized below:

A) It has been determined that after welding in atmospheric conditions, the grains become slightly thinner compared to the main structure, and after welding in water, they are oriented in the direction of cooling.

B) It was determined that the hardness values of the weld zone reached the maximum level after welding in water. On the other hand, as the depth of the weld increases, the hardness values decrease as a result of the increase in the amount of burning carbon.

C) As a result of grain size decrease after welding in atmospheric conditions, it was determined that the strength values increased compared to the main structure. After welding in water, it was determined that the strength and elongation values decreased compared to the main structure.

D) It was determined that the bending force increased as a result of increasing strength values after welding in atmospheric conditions. After welding in water, it was determined that both the bending force and the deflection values at the maximum bending force decreased.

E) While the impact toughness value of the main structure increased after welding in atmospheric conditions, it was determined that the impact toughness values decreased as a result of both decreasing strength and elongation values after welding in water.

ACKNOWLEDGEMENT

The authors would like to thank to Professor Gencaga Purcek (Mechanical Engineering Department, Karadeniz Technical University) for sharing his laboratory facilities.

REFERENCES

Bhadeshia, H.K.D.H. & Svensson, L. E. (1993). "Modelling the evolution of microstructure in steel weld metal". *Mathematical Modelling of Weld Phenomena, 1*, 109-182.

Boumerzoug, Z., Derfouf, C. & Baudin, T. (2010). "Effect of Welding on Microstructure and Mechanical Properties of an Industrial Low Carbon Steel". *Engineering, 2*(7), 502-506. doi:10.4236/eng.2010.27066.

David, S. A, Babu, S. S. & Vitek, J. M. (2003). "Welding: Solidification and Microstructure". *Jom, 55*(6), 14-20. doi:10.1007/s11837-003-0134-7.

Eroğlu, M., Aksoy, M. & Orhan, N. (1999). "Effect of coarse initial grain size on microstructure and mechanical properties of weld metal and HAZ of a low carbon steel". *Materials Science & Engineering: A, 269*(1-2), 59-66. doi:10.1016/S0921-5093(99)00137-9.

Gharibshahiyan, E., Raouf, A. H., Parvin, N. & Rahimian, M. (2011). "The effect of microstructure on hardness and toughness of low carbon welded steel using inert gas welding". *Materials & Design, 32*(4), 2042-2048. doi: /10.1016/j.matdes.2010.11.056.

Gould, J. E., Khurana, S. P. & Li, T. (2006). "Predictions of microstructures when welding automotive advanced high-strength steels". *Welding Journal, 85*(5), 111-116.

Grong, O. & Matlock, D. K. (1986). "Microstructural development in mild and low-alloy steel weld metals". *International Metals Reviews, 31*(1), 27-48. doi:10.1179/imtr.1986.31.1.27.

Hajian, M., Abdollah-zadeh, A., Rezaei-Nejad, S. S., Assadi, H., Hadavi, S. M.M., Chung, K. & Shokouhimehr, M. (2015). "Microstructure and mechanical properties of friction stir processed AISI 316L stainless steel". *Materials & Design, 67* (Supplement C), 82-94. doi:10.1016/j.matdes.2014.10.082.

Houldcroft, P. T. (1990). *Submerged-arc welding*. Woodhead Publishing.

İmdat, K., Kaya, Y. & Kahraman, N. (2018). "Grade A Gemi Sacının Örtülü Elektrod Ark Kaynak Yöntemi ile Sualtı ve Atmosferik Şartlarda Birleştirilebilirliğinin Araştırılması". *Politeknik Dergisi, 21*(3), 543-552.

Kanjilal, P., Pal, T.K., & Majumdar, S.K. (2006). "Combined effect of flux and welding parameters on chemical composition and mechanical properties of submerged arc weld metal". *Journal of Materials Processing Technology, 171*(2), 223-231.

Kanjilal, P., Pal, T.K., & Majumdar, S.K. (2007). "Prediction of element transfer in submerged arc welding". *Magnesium, 10,* 40.

Lars-Erik, S. (2017). *Control of microstructures and properties in steel arc welds*: CRC press.

Lee, C.S., Chandel, R.S., & Seow, H.P. (2000). "Effect of welding parameters on the size of heat affected zone of submerged arc welding". *Materials and Manufacturing Processes, 15*(5), 649-666.

Liu, F., Tan, C., Gong, X., Wu, L., Chen, B., Song, X., & Feng, J. (2020). "A comparative study on microstructure and mechanical properties of HG785D steel joint produced by hybrid laser-MAG welding and laser welding". *Optics & Laser Technology, 128*, 106247.

Magnabosco, I., Ferro, P., Bonollo, F., & Arnberg, L. (2006). "An investigation of fusion zone microstructures in electron beam welding of copper–stainless steel". *Materials Science and Engineering: A, 424*(1-2), 163-173.

McPherson, N.A., Chi, K., & Baker, T.N. (2003). "Submerged arc welding of stainless steel and the challenge from the laser welding process". *Journal of Materials Processing Technology, 134*(2), 174-179.

Murugan, N., & Gunaraj, V. (2005). "Prediction and control of weld bead geometry and shape relationships in submerged arc welding of pipes". *Journal of Materials Processing Technology*, *168*(3), 478-487.

Pandey, N.D, Bharti, A., & Gupta, S.R. (1994). "Effect of submerged arc welding parameters and fluxes on element transfer behaviour and weld-metal chemistry". *Journal of Materials Processing Technology, 40*(1-2), 195-211.

Zhang, Z., Jing, H., Xu, L., Han, Y., & Zhao, L. (2016). "Investigation on microstructure evolution and properties of duplex stainless steel joint multi-pass welded by using different methods". *Materials & Design, 109*, 670-685.